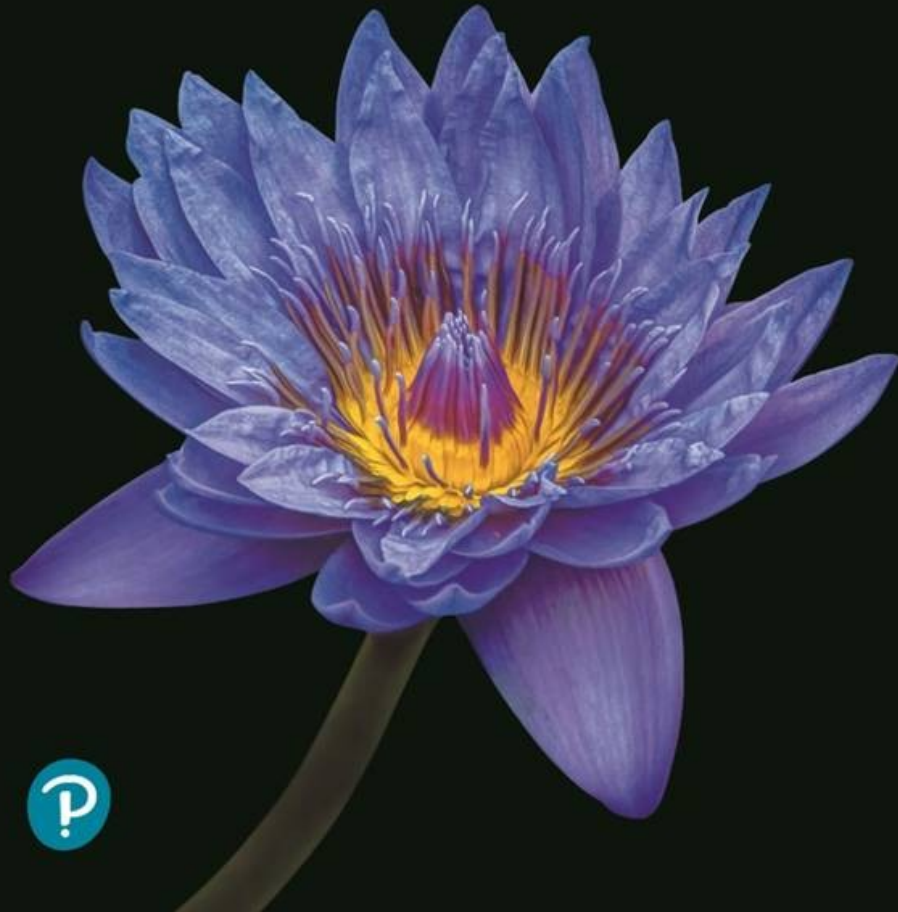


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Chapter 53

Population Ecology

Lecture Presentations by
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CONCEPT 53.1: Biotic and abiotic factors affect population density, dispersion, and demographics

Population

- a group of individuals of a single species living in the same general area
- described by their boundaries and size (number of individuals)
- Boundaries may be natural (a lake or island) or arbitrarily defined by an investigator (a county)

Density and Dispersion

Density - number of individuals per unit area or volume

- number of oak trees per square kilometer in the city of North Canton

Dispersion - pattern of spacing among individuals within the boundaries of the population

- Are they random, clumped or uniform?

Density: A Dynamic Perspective

- In most cases, it is impractical or impossible to count all individuals in a population
- Various sampling techniques can be used to estimate densities and total population sizes
 - Count the number of individuals in randomly located plots, calculate density in plots, extend to entire area
 - Use an indicator of population size, such as the number of nests, burrows, tracks, or fecal droppings
 - Use the **mark-recapture method**

Determining Population Size Using the Mark-Recapture Method

- Capture, tag, and release a random sample of individuals (**s**) in a population
- Marked individuals are given time to mix back into the population
- Capture a second sample of individuals (**n**), and note how many of them are marked (**x**)
- data collected is used to estimate population size (**N**) by applying the following formula:

$$\frac{x}{n} = \frac{s}{N} \quad \text{or, solving for population size,} \quad N = \frac{sn}{x}$$

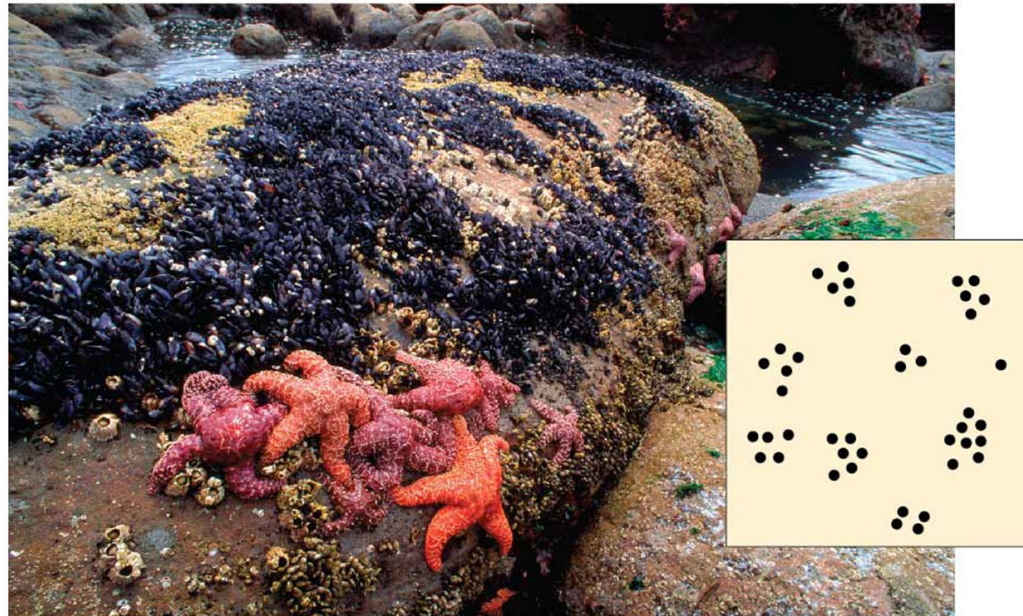
- Density is a dynamic property; it increases and decreases as individuals are added or removed
 - Increasing population size
 - **immigration** - influx of new individuals from other areas
 - births
 - Decreasing population size
 - **emigration** - movement of individuals out of a population
 - deaths

Pattern of dispersion

- Determined by the spacing among individuals within the boundaries of a population
- Differences in spacing can provide insight into the biotic and abiotic factors affecting individuals

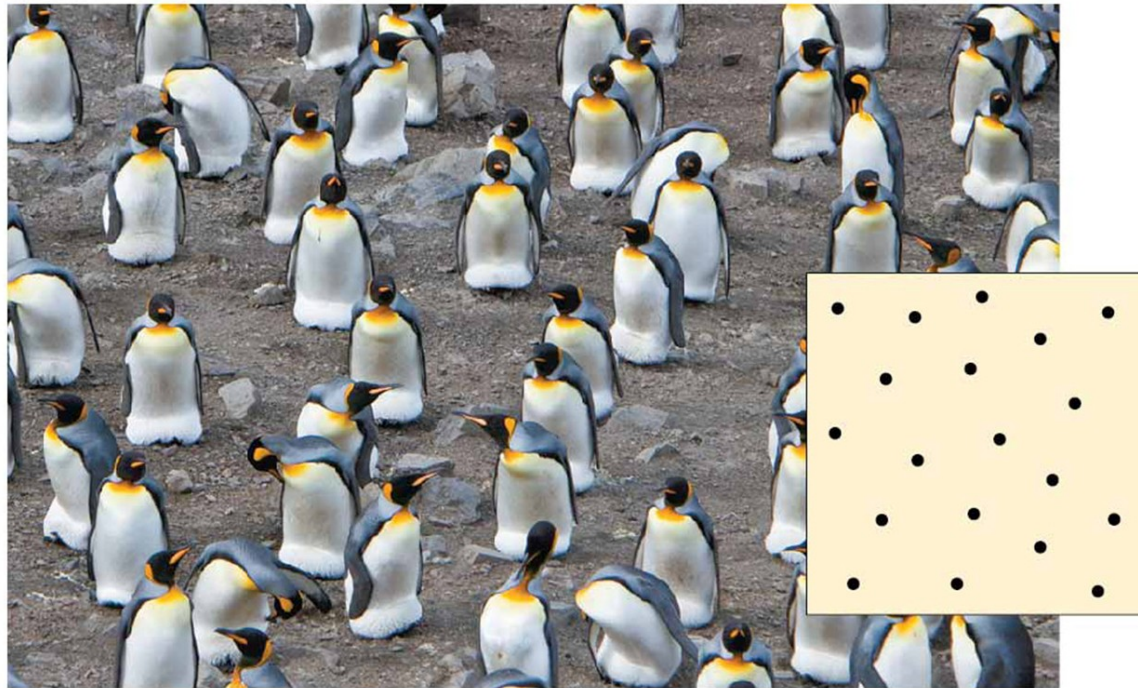
Clumped dispersion

- individuals aggregate in patches
- most common pattern of dispersion
- individuals may aggregate in areas of high resource availability or favorable physical conditions
- mating behavior and group predation or defense against predators can also influence clumped



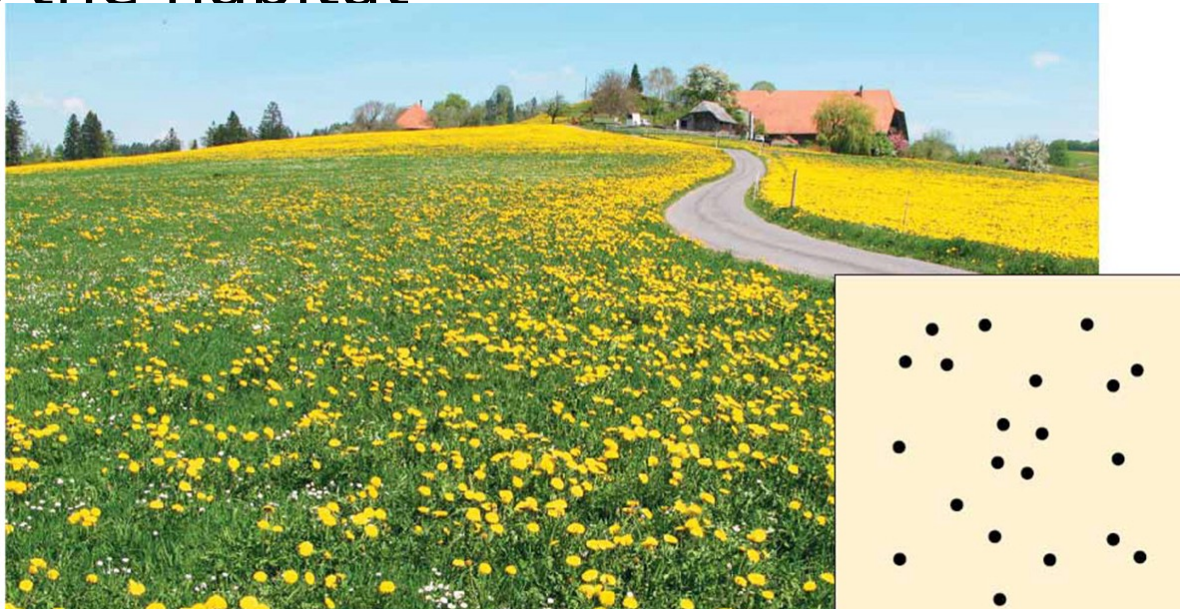
Uniform dispersion

- individuals are evenly spaced
- Some plants secrete chemicals that inhibit germination and growth of competing individuals
- Animals often exhibit **territoriality**, the defense of a bounded physical space against other



Random dispersion

- Position of each individual is independent of other individuals
 - unpredictable spacing
 - occurs in the absence of strong attractions or repulsions among individuals or constant distribution of key physical or chemical factors across the habitat



Demographics

- Biotic and abiotic factors influence birth, death, and migration rates of populations
- **Demography** is the study of these vital statistics of a population and how they change over time

Life Tables

- **Life table**

- age-specific summary of the survival and reproductive rates within a population
- often made by following a **cohort**, a group of individuals of the same age, from birth to death
- requires a method for determining the proportion of individuals surviving from one age-group to the next
- number of offspring produced by females in each age-group is needed
- males are often ignored because only females produce offspring

Table 53.1 Life Table for Female Belding's Ground Squirrels (Tioga Pass, in the Sierra Nevada of California)

Age (years)	Number Alive at Start of Year	Proportion Alive at Start of Year*	Death Rate†	Average Number of Female Offspring per Female
0–1	653	1.000	0.614	0.00
1–2	252	0.386	0.496	1.07
2–3	127	0.197	0.472	1.87
3–4	67	0.106	0.478	2.21
4–5	35	0.054	0.457	2.59
5–6	19	0.029	0.526	2.08
6–7	9	0.014	0.444	1.70
7–8	5	0.008	0.200	1.93
8–9	4	0.006	0.750	1.93
9–10	1	0.002	1.00	1.58

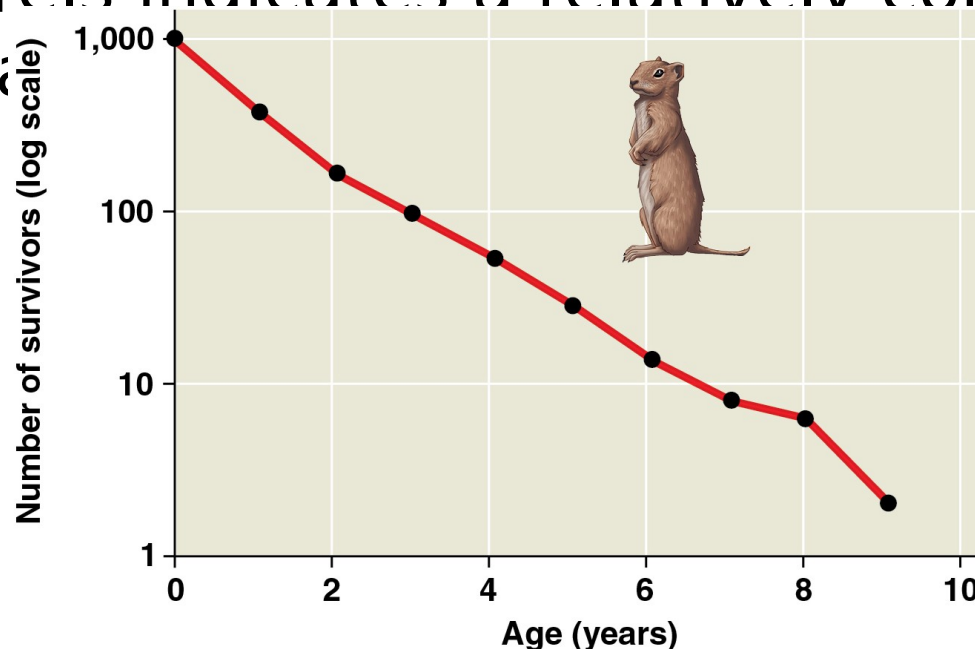
Data from P. W. Sherman and M. L. Morton, Demography of Belding's ground squirrel, *Ecology* 65: 1617–1628 (1984).

*Indicates the proportion of the original cohort of 653 individuals that are still alive at the start of a time interval.

†The death rate is the proportion of individuals alive at the start of a time interval that die during that time interval.

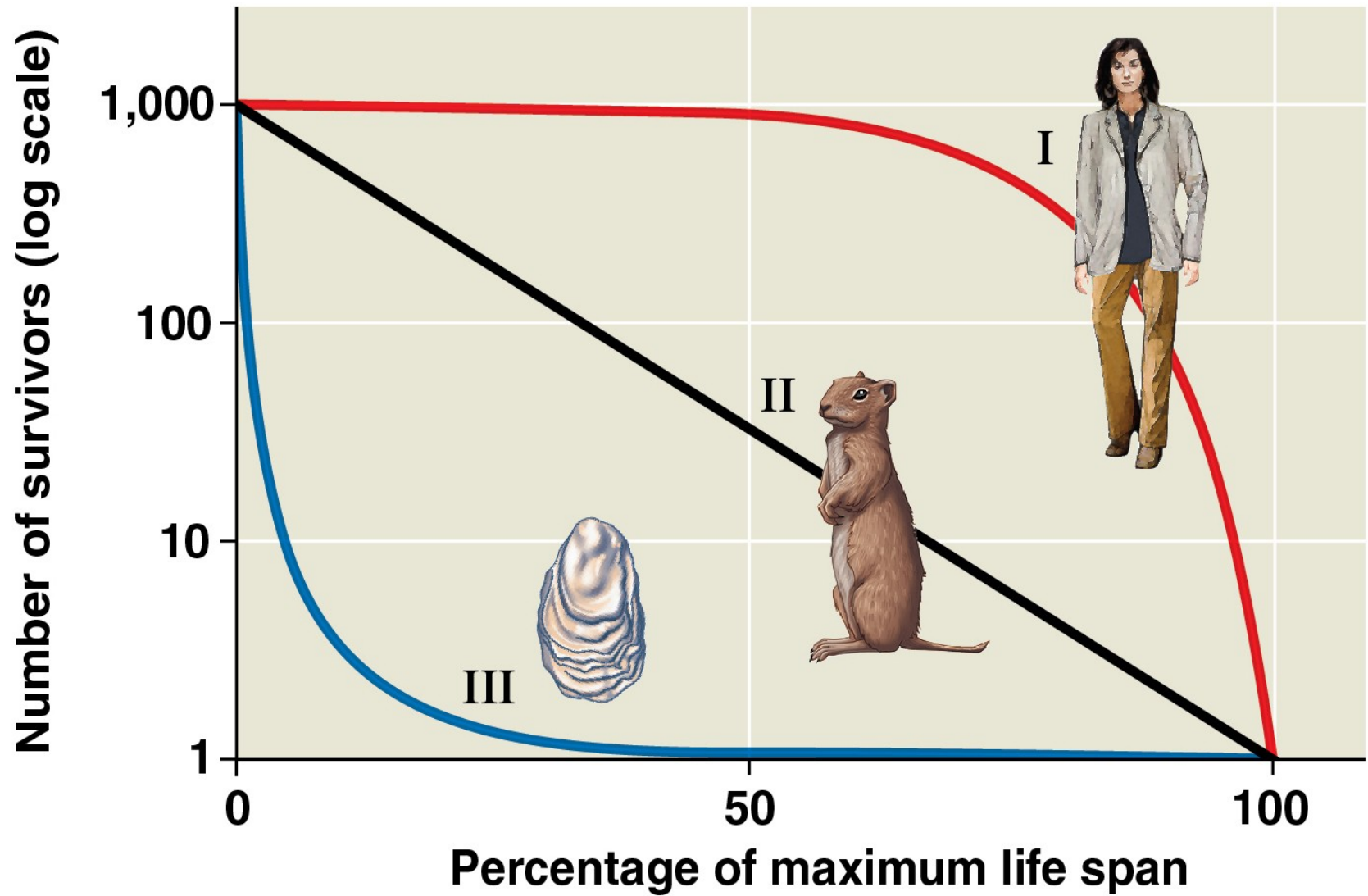
Survivorship curve

- plot of the proportion or numbers in a cohort still alive at each age
- shows the pattern of survivorship for a population
- approximately straight line of the survivorship curve for Belding's ground squirrels indicates a relatively constant rate of death



- Survivorship curves can be classified into three general types
 - **Type I:** Low death rates during early and middle life and a sharp increase in death rates later in life
 - Found in large mammals that produce few offspring but provide them with good care
 - **Type II:** Constant death rate over the life span
 - Found in some rodents, invertebrates, lizards, and annual plants
 - **Type III:** High death rates for the young; death rate steeply declines for survivors of early period die-off
 - Found in organisms that produce very large numbers of offspring but provide little or no care (for example, long-lived plants, many fishes, and most marine invertebrates)

Figure 53.5



- Many species are intermediate to these curves or show more complex patterns
 - For example, in birds, mortality is often high early in life (Type III) but fairly constant among adults (Type II)
- Survivorship curves can differ among populations within a single species

Reproductive Rates

- The reproductive pattern of a population is described by identifying how reproductive output varies with the number of breeding females and their ages
- Direct counts, mark-recapture, and molecular tools, such as DNA profiling, can be used to estimate the number of breeding females

- Reproductive output for sexual organisms is measured as the average number of female offspring produced by the females in an age group
- Age-specific reproductive rates vary considerably by species
 - For example, squirrels have one litter of two to six young per year for less than a decade, whereas oak trees drop thousands of acorns per year for tens or hundreds of years

CONCEPT 53.2: The exponential model describes population growth in an idealized, unlimited environment

- Populations of all species have the potential to expand greatly when resources are abundant
- In nature, unlimited growth is unsustainable because resources are depleted as the population gets larger
- Studying population growth under ideal conditions reveals how fast and under what conditions rapid growth can occur

Changes in Population Size

- Change in population size during a fixed time interval can be defined by the following verbal equation:

$$\begin{array}{ccccccc} \text{Change in} & & \text{Immigrant} & & & & \text{Emigrant} \\ \text{populatio} & = & \text{Births} & + & \text{S} & - & \text{Deaths} & - & \text{S} \\ \text{n} & & & & \text{entering} & & & & \text{leaving} \\ \text{size} & & & & \text{population} & & & & \text{populatio} \end{array}$$

- If immigration and emigration are ignored, the change in population size equals births minus deaths

- The population growth rate can be expressed mathematically as:

$$\frac{\Delta N}{\Delta t} = B - D$$

where ΔN is the change in population size, Δt is the time interval, B is the number of births, and D is the number of deaths during the time interval

- Population growth can also be expressed as a rate of change at each instant in time:

$$\frac{dN}{dt} = rN$$

- r is the **intrinsic rate of increase**, the per capita rate at which an exponentially growing population increases in size at each instant in time
 - r reflects the average contribution each individual makes to the population size during a time interval
 - N is the number of individuals in the population
- dN/dt represents very small changes in population size over short (instantaneous)

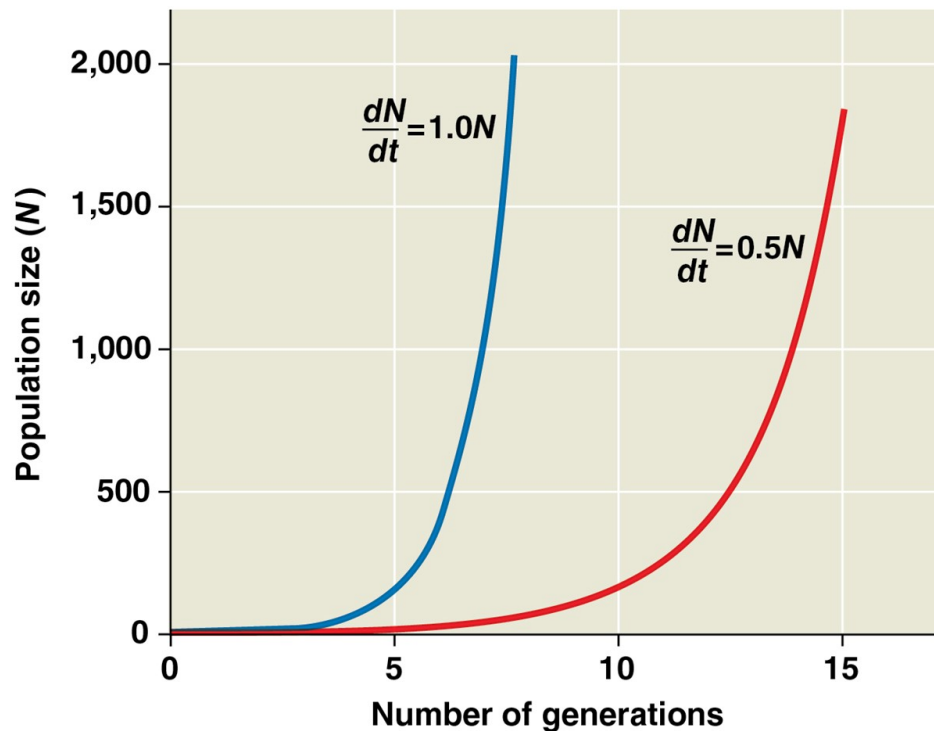
Exponential population growth

- occurs under ideal conditions
- all individuals have access to abundant food
- reproduce at physiological capacity
- Under such conditions, populations may increase in size by a constant proportion at each instant

The equation of exponential population growth is:

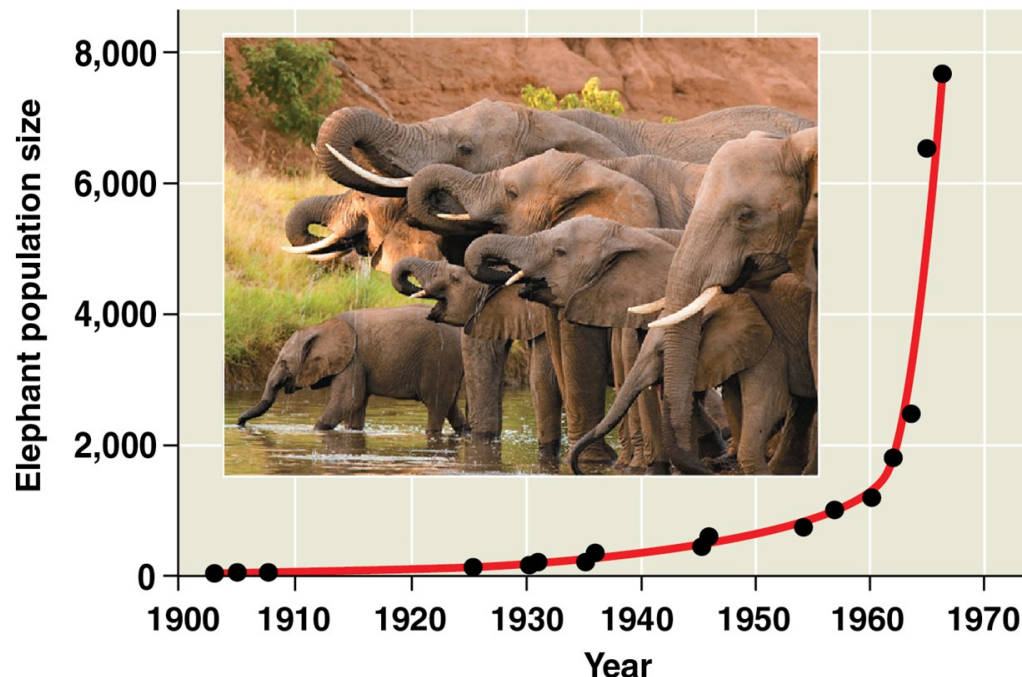
$$\frac{dN}{dt} = rN$$

- Exponential population growth
 - results in a J-shaped curve when population size is plotted over time
 - per capita rate of increase is constant, but more new individuals are added per unit time when the population is large than when it is small



Exponential population growth

- characteristic of populations that are introduced to a new environment
- may represent populations that are rebounding after drastic reduction by a catastrophic event
 - For example, the elephant population in Kruger National Park, South Africa, grew exponentially after



CONCEPT 53.3: The logistic model describes how a population grows more slowly as it nears its carrying capacity

- The exponential growth model assumes resources will remain abundant as population size increases
- In nature, each individual has access to fewer resources as population size increases
- Realistic models of population growth incorporate **carrying capacity** (K), the maximum population size that a particular environment can sustain

- Carrying capacity varies over space and time with the abundance of limiting resources
- Energy, shelter, refuge from predators, nutrient availability, water, and suitable nesting sites are all limiting factors

- Crowding and resource limitation will affect the per capita birth and death rates, causing the per capita rate of population growth (r) to drop
 - Per capita birth rates decline when individuals cannot obtain sufficient resources to reproduce
 - Per capita death rates increase if starvation or disease increases with density

The Logistic Growth Model

- In the **logistic population growth** model, the per capita rate of population growth approaches zero as the population size nears carrying capacity (K)
- The logistic model starts with the exponential model and adds an expression that reduces per capita rate of population growth as population size (N) increases

$$\frac{dN}{dt} = rN \frac{(K - N)}{K}$$

- When N is small compared to K , the term $(K - N)/K$ is close to 1, and the per capita rate of population growth will be close to r
- When N is large and resources are limiting, the term $(K - N)/K$ is close to 0, and the per capita rate of population growth is small
- When N equals K , the population stops growing

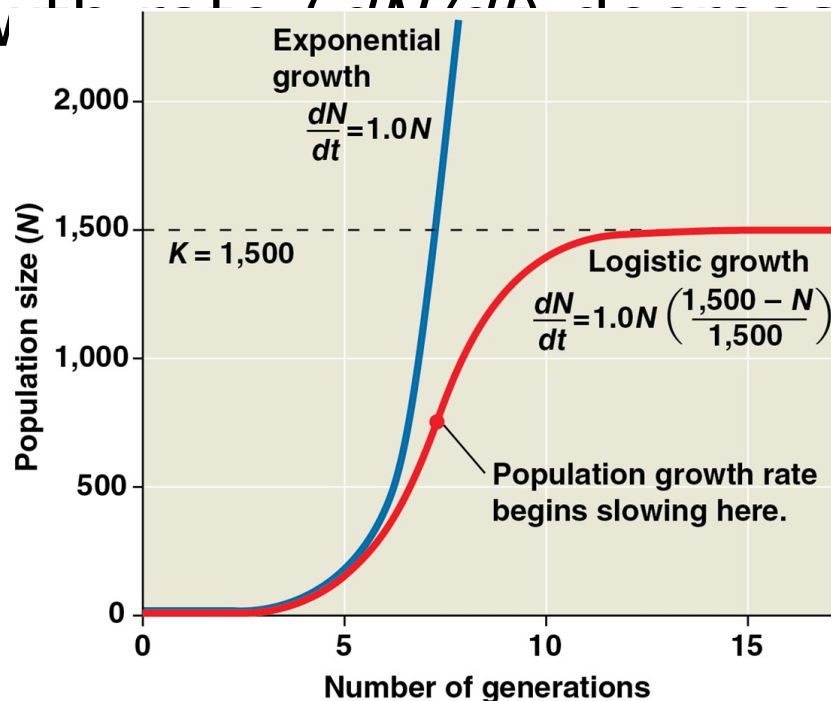
**Table 53.2 Logistic Growth of a Hypothetical Population
($K = 1,500$)**

Population Size (N)	Intrinsic Rate of Increase (r)	$\frac{K - N}{K}$	Per Capita Population Growth Rate, $r \frac{(K - N)}{K}$	Population Growth Rate,* $rN \frac{(K - N)}{K}$
25	1.0	0.983	0.983	+25
100	1.0	0.933	0.933	+93
250	1.0	0.833	0.833	+208
500	1.0	0.667	0.667	+333
750	1.0	0.500	0.500	+375
1,000	1.0	0.333	0.333	+333
1,500	1.0	0.000	0.000	0

***Rounded to the nearest whole number.**

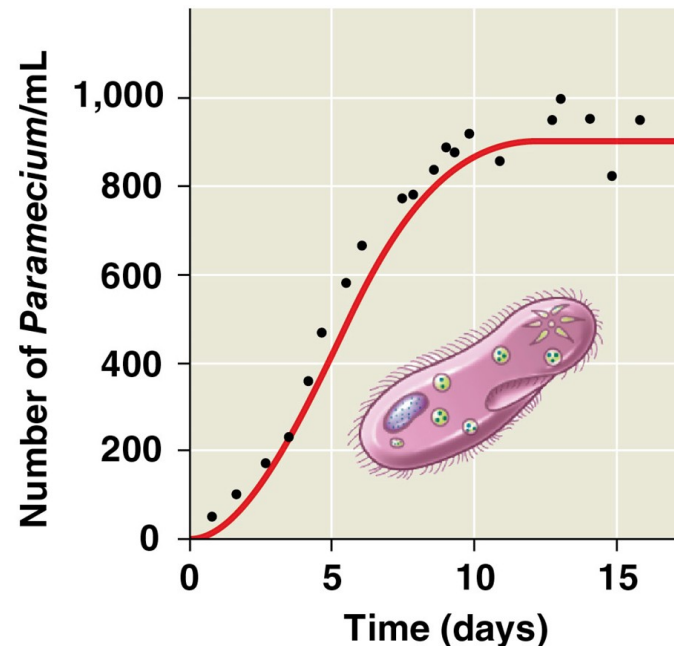
- Logistic model

- produces a sigmoid (S-shaped) curve when population size (N) is plotted over time
- individuals are added most rapidly at intermediate population size, when the breeding population is substantial and resources are abundant
- population growth rate begins to slow as N approaches K



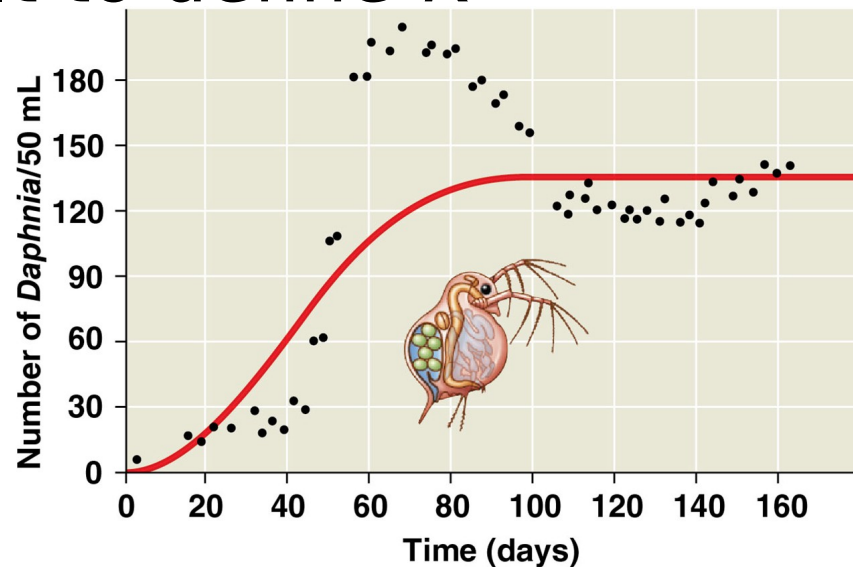
The Logistic Model and Real Populations

- Growth of laboratory populations of some small animals and microorganisms fit an S-shaped curve if resources are limited
- These populations are grown in a constant environment lacking predators and competitors



(a) A *Paramecium* population in the lab

- Some populations overshoot K before settling down to a relatively stable density
 - For example, if food becomes limiting, females may use energy reserves to continue reproducing; birth rates will decline when reserves are depleted
- Other populations fluctuate greatly and make it difficult to define K



(b) A *Daphnia* population in the lab

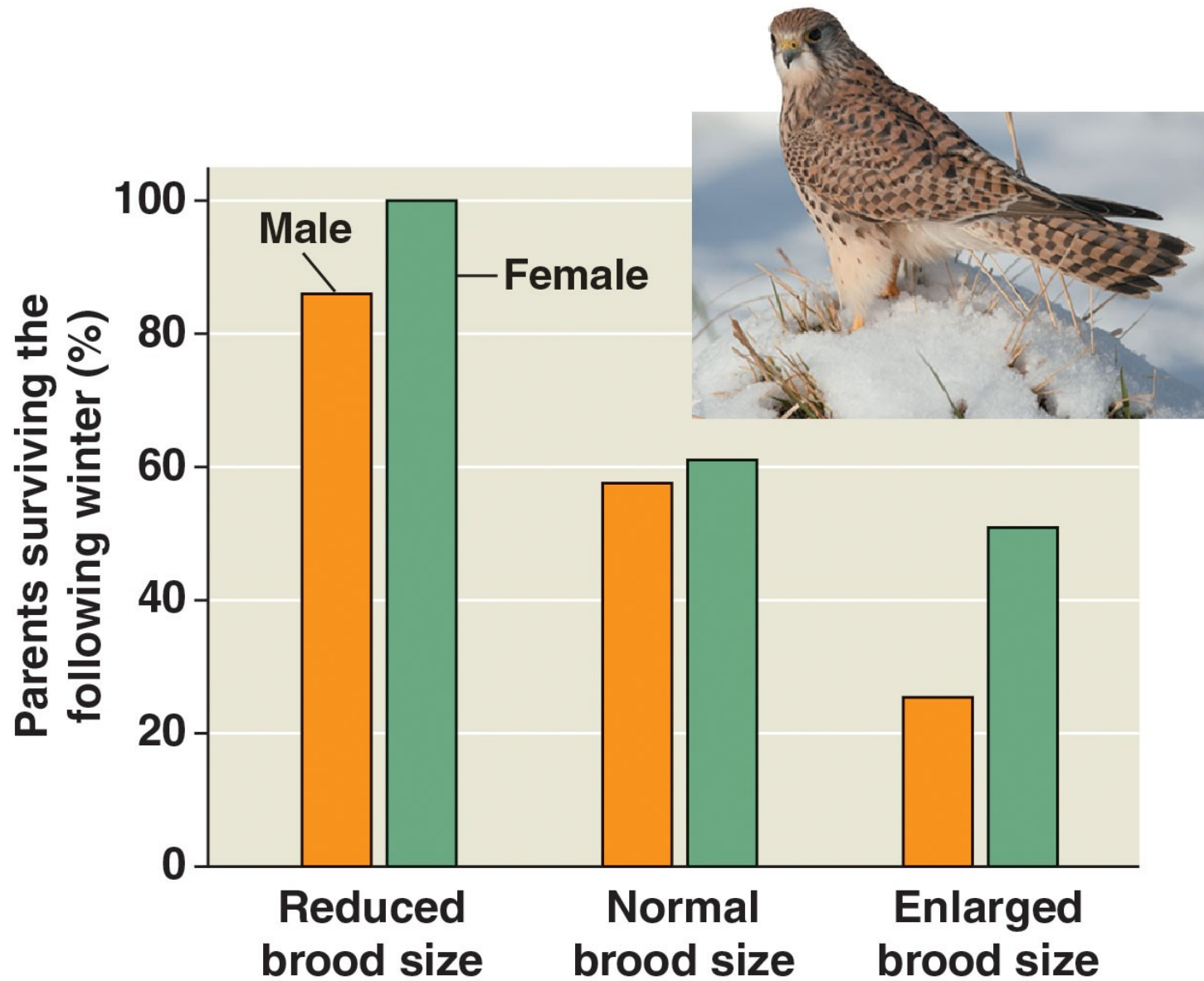
- Conservation biologists use the logistic growth model for several applications
 - Predicting rate of recovery for small populations
 - Estimating sustainable harvest rates for wildlife
 - Estimating population growth rate



CONCEPT 53.4: Life history traits are products of natural selection

- An organism's **life history** comprises the traits that affect its schedule of reproduction and survival
- Life history traits are evolutionary outcomes reflected in the development, physiology, and behavior of an organism

Figure 53.13



- Selective pressures influence trade-offs between the number and size of offspring
- Species whose young have a low chance of survival often produce many small offspring
 - plants that colonize disturbed environments, such as dandelions, usually produce many small seeds
- In some species, parents produce relatively few offspring and invest more energy in each offspring to increase the probability of survival for each
 - Brazil nut trees produce large seeds packed with nutrients that help seedlings become established

- Variation in life history traits can be related to the logistic growth model
 - ***K-selection*** - selection for life history traits that are advantageous when density is high (near K), resources are low, and competition is strong
 - ***r-selection*** - selection for life history traits that maximize reproductive success when density is low and there is little competition for resources
- These concepts represent two extremes in a range of actual life histories

CONCEPT 53.5: Density-dependent factors regulate population growth

- Answers to the following questions are important in practical applications:
 - What environmental factors stop a population from growing indefinitely?
 - Why are some populations fairly stable in size, while others are not?

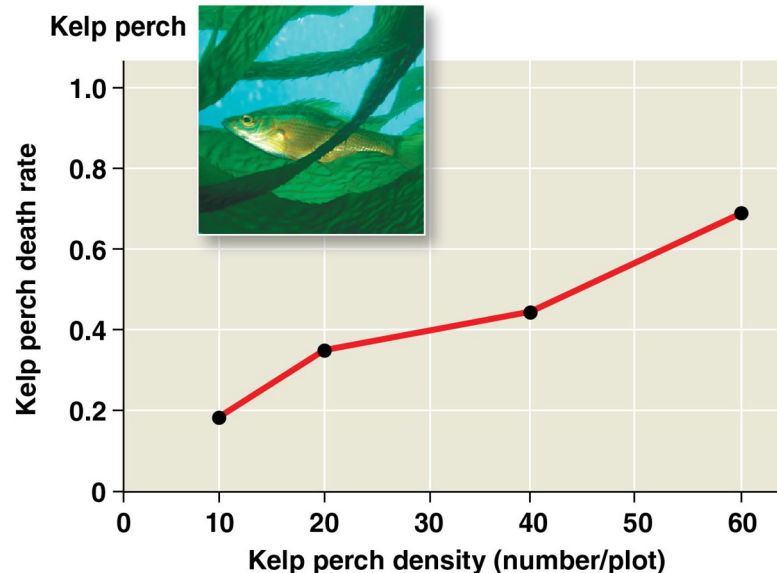
Population Change and Population Density

- Assuming immigration and emigration offset each other, a population will
 - grow when the birth rate exceeds the death rate
 - decline when the death rate exceeds the birth rate
- A birth rate or death rate that does not change with population density is **density independent**

- If a death rate increases or a birth rate decreases with increasing density, it is **density dependent**
- A population is regulated when one or more density-dependent factors cause it to decrease when large (or increase when small)
- Density-independent factors cannot regulate population size

Mechanisms of Density-Dependent Population Regulation

- Density-dependent birth and death rates are an example of negative feedback that regulates population growth
 - For example, in a study of kelp perch populations, the death rate increased as hiding spaces from predators became scarce at high



- In addition to predation, several other mechanisms can cause density-dependent regulation:
 - Competition for resources
 - Disease
 - Intrinsic factors
 - Territoriality
 - Toxic wastes

Competition for Resources

- Increasing population density intensifies competition for resources and reduces birth rates
 - farmers reduce competition by applying



Disease

- can regulate population density if its transmission rate increases as the population becomes more crowded
 - influenza (flu) and tuberculosis affect a greater percentage of people in densely populated cities than in less populated areas



Territoriality

- can limit population density when space becomes the resource for which individuals compete
 - cheetahs use chemical markers in urine to
- wa
bo



Intrinsic Factors

- For some populations, intrinsic (physiological) factors appear to regulate population size
 - hormonal changes in white-footed mice delay sexual maturation and depress the immune system at high density
 - birth rates decline when food and shelter are abundant



Toxic Wastes

- Accumulation at high population density can contribute to density-dependent regulation of population size
 - the concentration of ethanol produced by brewer's yeast becomes toxic at high population density



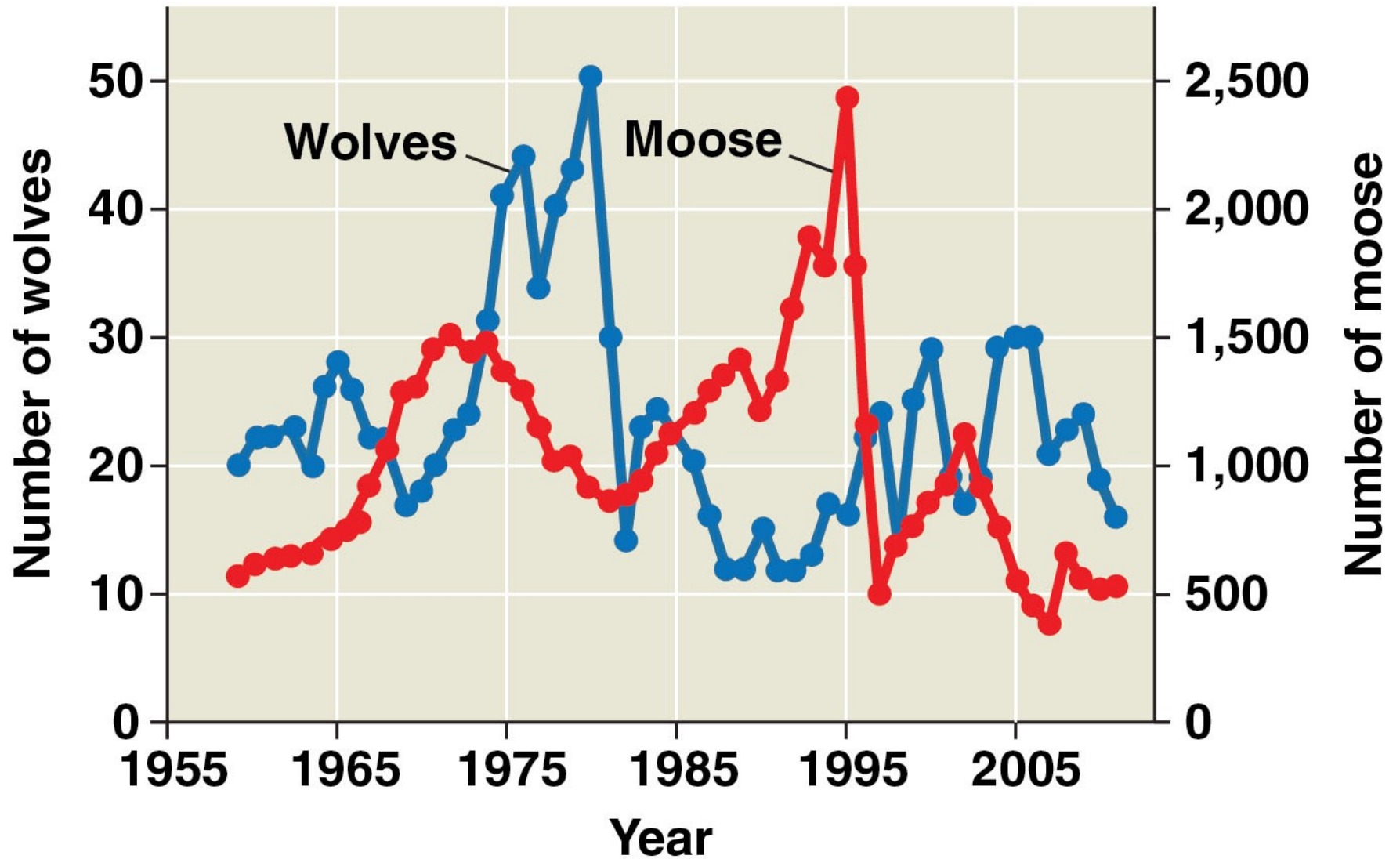
Population dynamics

- focuses on the complex interactions between biotic and abiotic factors that cause variation in population size

Stability and Fluctuation

- Populations of large mammals were once thought to be relatively stable, but long-term studies show that they can fluctuate substantially
 - there have been two major population increases and collapses in the moose population on Isle Royale during the last 50 years
 - first collapse coincided with a peak in the wolf population
 - second with harsh winter conditions

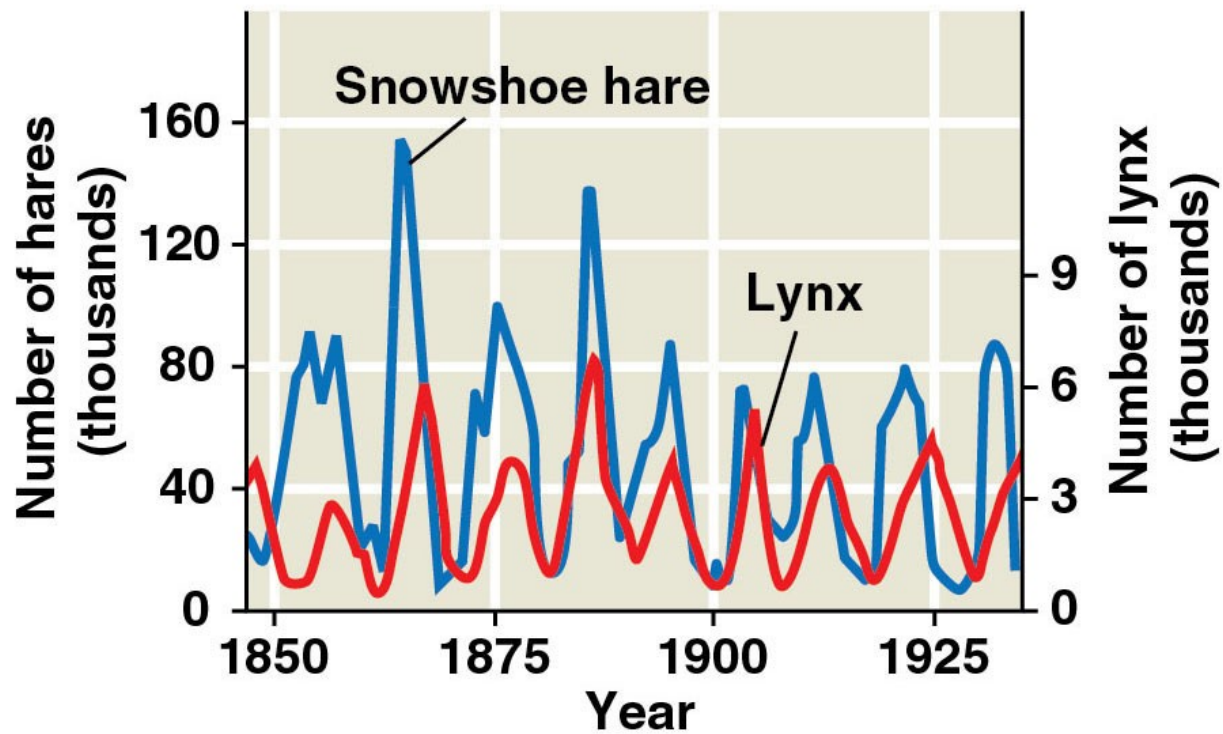
Figure 53.18



Population Cycles: *Scientific Inquiry*

- While many populations fluctuate at unpredictable intervals, others undergo regular boom-and-bust cycles
 - snowshoe hares and lynx both follow roughly 10-year population cycles in the forests of northern Canada and Alaska

Figure 53.19



Immigration, Emigration, and Metapopulations

- In addition to births and deaths, immigration and emigration also influence populations
- When a population becomes crowded and resource competition increases, emigration often increases

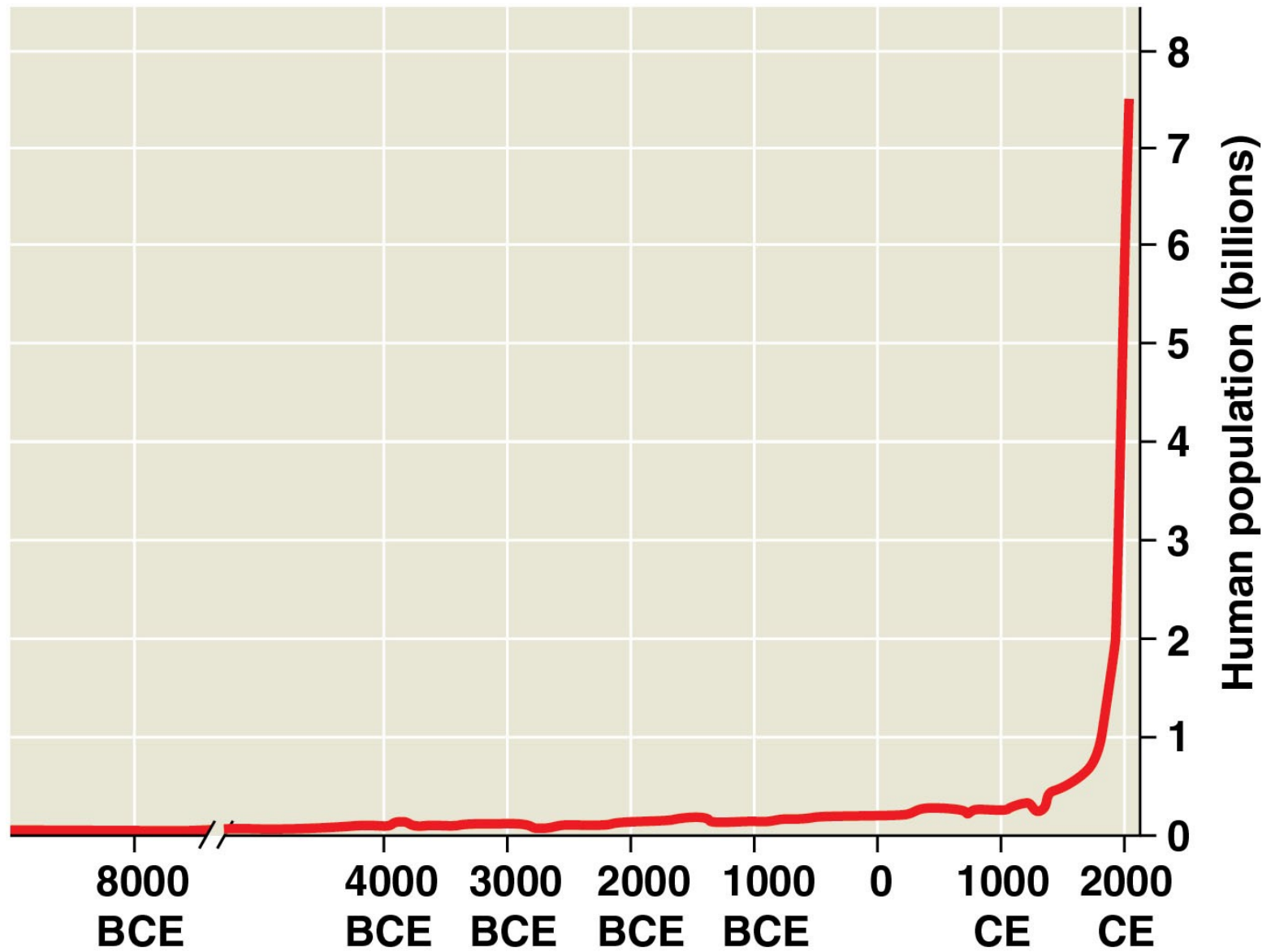
CONCEPT 53.6: The human population is no longer growing exponentially but is still increasing extremely rapidly

- In the last few centuries, the human population has grown at an unprecedented rate
- No population can grow indefinitely, and humans are no exception

The Global Human Population

- The human population has grown explosively over the last four centuries
- The time required for the population to double in size decreased from 200 years in 1650 to just 45 years in 1975
- This is faster than exponential growth, which has a constant rate of increase and a constant doubling time

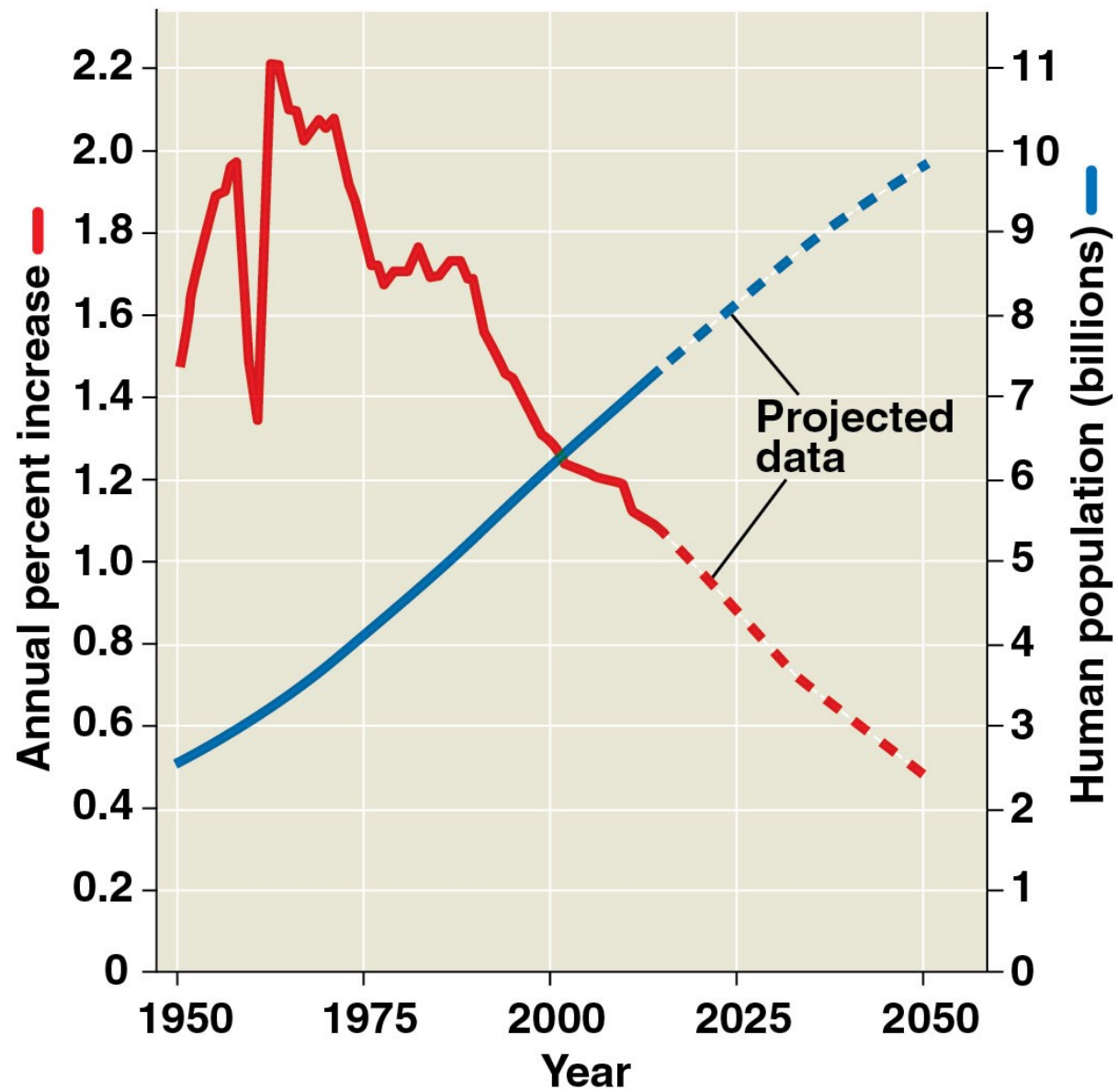
Figure 53.21



- The global population is now more than 8.2 billion people and is increasing by 80 million per year, or more than 200,000 people per day
- It is predicted to reach 9.8 billion by the year 2050

- Though the global population is still growing, the rate of growth began to slow during the 1960s
- The annual rate of increase peaked at 2.2% in 1962, but was only 1.1% in 2018
- Current models project a growth rate of 0.5% by 2050, adding 49 million more people per year if the population reaches the projected 9.8 billion

Figure 53.22



Infant Mortality and Life Expectancy

- Infant mortality and life expectancy at birth vary widely in different countries and can influence reproductive choices by parents
- Global life expectancy been increasing since 1950
- Social upheaval, decaying infrastructure, and disease have reduced life expectancy in some countries

Global Carrying Capacity

- Population ecologists predict a global population of 9.8 billion people in 2050
- How many humans can the biosphere support?

Estimates of Carrying Capacity

- The carrying capacity of Earth for humans is uncertain; estimates have varied from less than 1 billion to more than 1,000 billion (1 trillion)
- Scientists have based estimates on logistic growth models, area of habitable land, and food availability

Limits on Human Population Size

- Humans require food, water, fuel, building materials, and other resources such as clothing and transport
- The **ecological footprint** concept summarizes the aggregate land and water area needed to sustain a person, city, or nation

- One way to estimate the footprint is to add up all productive land and divide by the number of people
- This allots 1.7 global hectares (gha) per person; any more is unsustainable
- Countries vary greatly in footprint size; the average per person is 8 gha in the United States and 2.7 gha globally
- This overshoots sustainable use by more than 50%

- Ecological footprints can also be calculated using energy use
- Average energy use differs greatly across different regions of the world
 - For example, a typical person in the United States, Canada, or Norway consumes about 30 times the energy of a person in central Africa

- Fossil fuels are the source of 80% or more of the energy used in most developed nations
- Reliance on fossil fuels is changing Earth's climate and increasing the amount of waste humans produce

- Our carrying capacity may also be limited by food, space, nonrenewable resources, or waste production
- Humans could choose to regulate population growth through social change
- Otherwise, it will happen through increased mortality due to resource limitation, plagues, war, and environmental degradation